Environmental assessment of the measures increasing the sustainability of motor transport

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Abstract. Ensuring the sustainable development of motor transport, whose emission of greenhouse gases and other contaminants is one of the main sources of air pollution, requires informed decision-making on the implementation of effective environmental protection measures. A simplified methodological approach to a comparative assessment of the effectiveness of these environmental protection measures has been developed. The offered approach has been approved at estimating application for motor fuels of the multipurpose additive, which increases both the energy efficiency and environmental safety of motor transport.

1. Introduction

Despite the advantages that modern society derives from the use of transport, technological progress achieved and the tightening of emissions standards, automotive transport remains one of the main sources of pollution by toxic substances and greenhouse gases, detrimental to human health. Vehicle emissions create increased concentrations of pollutants, especially in cities where their contribution to air pollution in the breathing zone is significantly higher than that from other sources.

Apparently, emissions from vehicles of of benzo(α)pyrene and its analogues – polycyclic aromatic hydrocarbons, which are the strongest of all carcinogens, is the most serious problem. Emissions of polycyclic aromatic hydrocarbons are maximal in idle running, i.e. near traffic lights, and thus they come directly to the breathing zone of people, while their content in exhaust gases exceeds the maximum allowable concentrations (MAC) level by an order of magnitude [1, 2]. Due to the high boiling point (310 °C at 1.33 kPa for benzo(α) pyrene) and chemical inertness, these hydrocarbons are adsorbed on the road surfaces, soil, etc. Figure 1 shows dynamics of average annual concentrations of benzo(α)pyrene on average throughout Russia in 2011–2015; figure 2 shows dynamics of lung cancer incidence in 2004–2014. In large cities, the concentration of benzo(α)pyrene exceeds the MAC to a significantly greater degree. There is an increase in the average incidence (by about 20 % over 10 years) despite a decrease in the level of benzo(α)pyrene concentrations over the past 5 years, which is explained by both the cumulative effect of harmful influence and synergistic effect of various factors.

To reduce the environmental footprint of the transport sector various instruments and methods are used, including upgrading road infrastructure [5], rational organization of road traffic [6, 7], improvement of the engines and cars' design [8, 9], and the use of fuels with improved environmental characteristics [10–14]. Methods to improve the sustainability of motor transport are characterized by their differences in timing, efficiency and costs for their implementation.

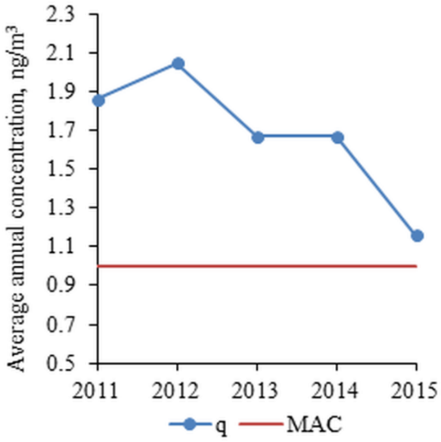


Figure 1. Dynamics of average annual concentrations of benzo(α)pyrene (q, ng/m^3) in Russian cities, relative to the level of daily average maximum allowable concentration, MAC (according to [3])

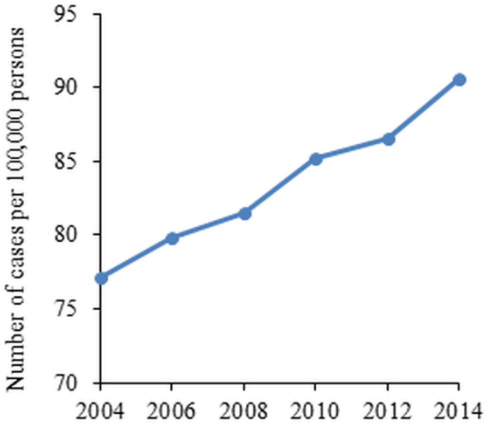


Figure 2. Dynamics of lung cancer incidence in Russia (according to [4])

In order to rapidly implement highly efficient technological solutions that increase the environmental sustainability of motor transport it is necessary to compare possible alternative scenarios with an assessment of externalities and costs. Given the difficulty of fully accounting for externalities, it seems important to use simplified procedures for assessing the feasibility of implementing the environmental measures that can identify the dominant effects of implementation.

2. Methodical approach to accounting for externalities of the motor transport operation and assessment of the effectiveness of the environmental protection measures

Exhaust gases of vehicles contain a significant enumeration of toxic substances that directly enter human's breathing zone. At the same time, the contribution of various components of the exhaust gases to the total toxicity varies significantly; thus the ratio of gross emissions without taking into account the toxicity of the components does not adequately characterize the level of the negative impact as a whole, nor does it allow the contribution of the individual pollutants to be readily estimated to the total toxicity of the exhaust gases. Conversion into the conditional mass units while taking into account the relative environmental hazard allows one to solve this problem and calculation of the equivalent mass *G*, conventional ton, can be made using the formula (1):

$$G = \sum_{i=1}^{N} G_i \cdot K_i \quad , \tag{1}$$

where G_i is the actual mass of the i-th pollutant, entering the atmospheric air during the reporting period, calculated in tons; K_i is the coefficient of the relative environmental hazard of the i-th pollutant, calculated as the reciprocal value of the maximum allowable concentration of the i-th pollutant (MAC_i), conventional ton per ton.

The relative environmental hazard of emission components should be taken into account when calculating the atmospheric air damage (for example, in Russia this approach was used in [15], equation (2)):

$$D_{ps}^{el} = d_{sp} \cdot G \cdot K_e \cdot J_d \tag{2}$$

where D_{ps}^{el} is the environmental damage from polluting toxic substances emission to the atmospheric air, monetary units per year; d_{sp} is the index of specific atmospheric air damage caused by emission of the mass unit of a pollutant, monetary units per conventional ton; K_e is the coefficient of the environmental situation and environmental significance of the state of the atmospheric air for a given district; J_d *is* a deflator index used for damage index calculation from the current price to the base (comparable) one.

In the environmental assessment of implementation of the specified environmental measure relative to the basic situation, the effectiveness of the environmental protection measure e_{ps}, %, concerning the reduction of emissions of polluting toxic substances and prevention of the corresponding environmental damage during the reporting period can be determined according to the formula (3):

$$e_{ps} = \frac{D_{ps0}^{el} - D_{ps1}^{el}}{D_{ps0}^{el}} \cdot 100\% = \frac{G_0 - G_1}{G_0} \cdot 100\% = \frac{\Delta G}{G_0} \cdot 100\% \tag{3}$$

where D_{ps0}^{el}, D_{ps1}^{el} is the environmental damage from the atmospheric air pollution by the emissions of polluting toxic substances, and G_0, G_1 is the equivalent mass of the emissions, accordingly, in the base case and after implementation of the environmental protection measure; ΔG – the prevented equivalent mass of the emissions of polluting toxic substances after implementation of the environmental protection measure.

Thus, in order to assess possible scenarios aimed at reducing the damage from emissions of polluting toxic substances a relative change in the equivalent mass of the pollutants should be taken into account. It is thus possible to evaluate the impact of the environmental protection measure on the emissions of the individual pollutant and prevention of the corresponding environmental damage caused by the specified component of the emissions.

For a more complete accounting for externalities of the motor transport operation when evaluating the atmospheric air damage it had been previously suggested to take into account the negative effects caused by not only emissions of polluting toxic substances, but also carbon dioxide emissions as well as the consumption of atmospheric oxygen. Formulas have been proposed for calculating the environmental damage from carbon dioxide emissions $D_{CO_2}^{el}$, and from consumption of oxygen during combustion of fuel, $D_{O_2}^{el}$ [16]. When all the constants are combined, these harmful contributions can be estimated, respectively, according to the equations (4) and (5):

$$D_{CO_2}^{el} = d_{CO_2} \cdot a \cdot J_d \cdot G_f \tag{4}$$

where d_{CO_2} is the specific environmental damage from the emission to the atmospheric air of 1 ton of carbon dioxide, monetary units per ton; G_f is the actual mass of the fuel consumed during the reporting period, calculated in tons; a is the constant.

$$D_{O_2}^{el} = b \cdot J_d \cdot G_f \, , \tag{5}$$

where b is the constant. In the environmental assessment of the environmental protection measure's impact on the environmental damage from carbon dioxide emissions, and on the environmental damage from oxygen consumption, relative to the basic case, the effectiveness of environmental protection measures e_{CO_2}, % to reduce carbon dioxide emissions during the reporting period, and efficiency e_{O_2}, %, to reduce consumption of oxygen, at the different absolute values of the corresponding damages prevented, will be equal according to the equations (6) and (7):

$$e_{CO_2} = \frac{D^{el}_{CO_{2}0} - D^{el}_{CO_{2}1}}{D^{el}_{CO_0}} \cdot 100\% = \frac{G_{f\,0} - G_{f\,1}}{G_{f\,0}} \cdot 100\% = \frac{\Delta G_f}{G_{f\,0}} \cdot 100\% \tag{6}$$

$$e_{O_2} = \frac{D^{el}_{O_{2}0} - D^{el}_{O_{2}1}}{D^{el}_{O_0}} \cdot 100\% = \frac{G_{f\,0} - G_{f\,1}}{G_{f\,0}} \cdot 100\% = \frac{\Delta G_f}{G_{f\,0}} \cdot 100\% \tag{7}$$

Thus, in order to assess possible scenarios to reduce damage from carbon dioxide emissions and from consumption of oxygen in the combustion process, the fuel consumption changes should be taken into account.

This approach is also applicable when comparing alternative options for the environmental protection measures.

3. Environmental assessment of application of the multifunctional additive to motor fuels as a method to increase environmental sustainability of motor transport

For different countries their differing priorities can mean their directions to improve the environmental sustainability of vehicles can differ. Meanwhile, the use of highly effective additives that improve the properties of hydrocarbon fuels is a quick and inexpensive way to solve this problem and therefore, it is promising for both developed and developing countries.

The multifunctional all-purpose additive for fuels [12, 17] has a complex positive effect on the environmental and performance characteristics of vehicles using gasoline and diesel fuel at the very low cost of the method equal to $ 1per ton of gasoline and $ 3 per ton of diesel fuel. To assess the environmental effectiveness of the additive application using the proposed simplified approach, the significant factors, which should be taken into account, are the effect of the additive on pollutant emissions and fuel consumption, Table 1.

Table 1. Effect of the multifunctional additive application in optimal concentrations on the polluting substances' emissions and fuel consumption

Characteristics	Vehicles with gasoline engines	Vehicles with diesel engines
Reduction of emission, on average		
CO	–23 %	–16 %
NO_x	–23 %	–21 %
C_mH_n	–22 %	–36 %
benzo(a)pyrene and its analogs	–95 %	–
$PM_{2.5}$	–	–45 %
Fuel consumption, on average	–10 %	–6 %

In the retrospective assessment of the application of the environmental protection measure proposed in Russia, we assume that in the reporting period (2010–2015) the emissions of the standard pollutants (CO, NO_x, C_mH_n, $PM_{2.5}$) of all vehicles meet the Euro-3 standards. The data on fuel consumption were used to determine the annual amount of emissions [18], the relative hazard coefficients K_i, conventional tons per ton, of the specified pollutants were taken to be equal, according to the procedure [15], to 0.4 for CO, 16.5 for NO_x, 0.7 for C_mH_n, 33.5 for $PM_{2.5}$. Figure 3 demonstrates the effect of the additive on the equivalent mass of the sum of these pollutants. Figure 4 shows the change in the case of the individual pollutants, taking into account the relative toxicity of emissions.

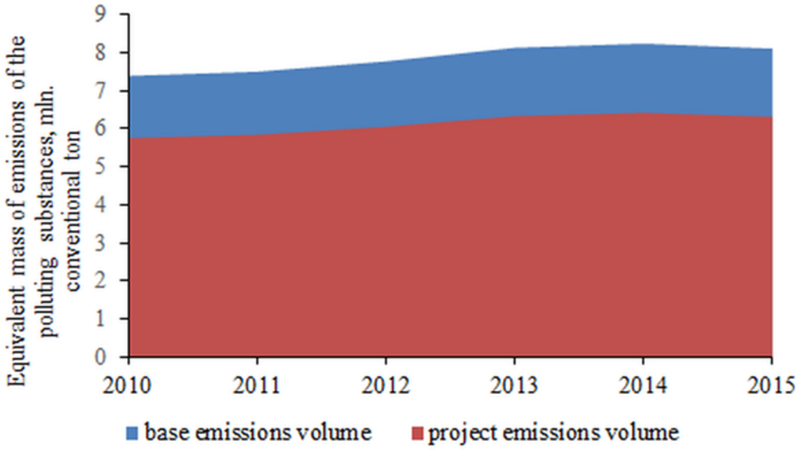
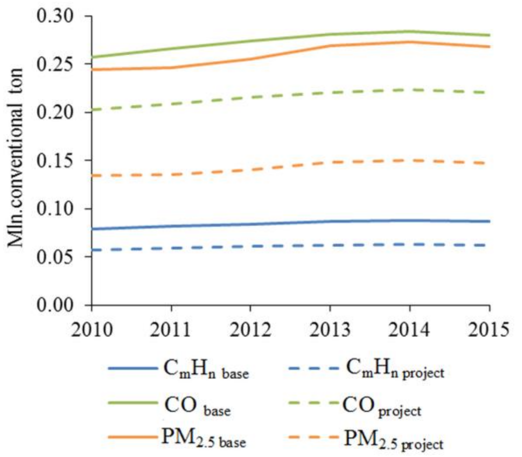
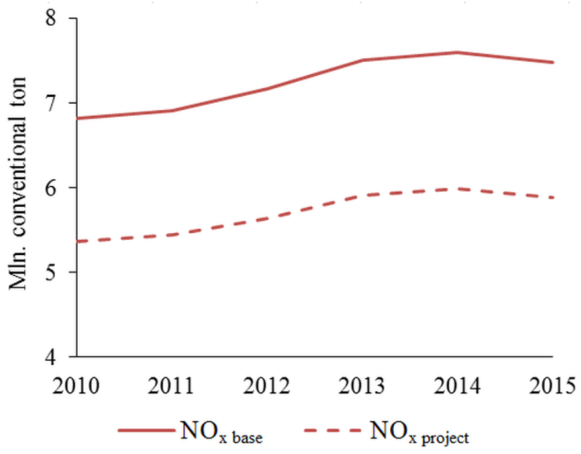


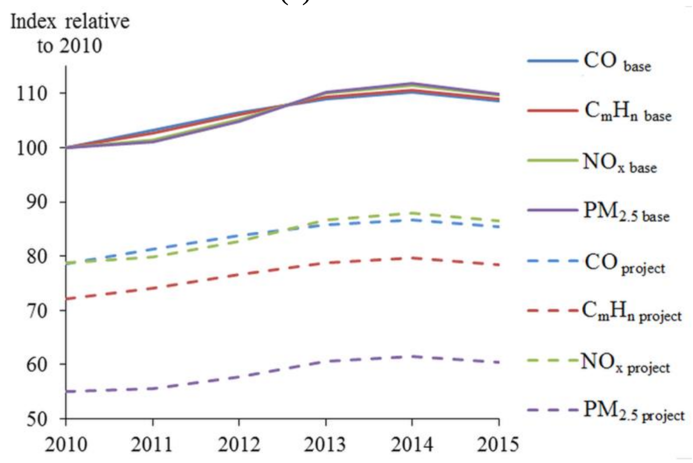
Figure 3. Change to the equivalent total emissions of CO, NO_x, C_mH_n, $PM_{2.5}$ after implementation of the environmental protection measure relative to the base scenario



(a)



(b)



(c)

Figure 4. Dynamics of the equivalent mass of the emission components: (a) – CO, C_mH_n, $PM_{2.5}$, (b) – NO_x, and of the equivalent mass indexes (c) after implementation of the environmental protection measure relative to the base scenario

It should be noted that the relative toxicity of benzo(α)pyrene ($C_{20}H_{12}$),which is the strongest carcinogen, is significantly higher than that of the gaseous toxic components of emissions and particulate matter, and according to the procedure of [15] it is assumed to be 12,500 conventional tons per ton. It is advisable to calculate the effectiveness of the implementation of this environmental measure for the reduction of the amount of CO, NO_x, C_mH_n, $PM_{2.5}$ and benzo(α)pyrene emissions separately. Figure 5 shows the calculated effectiveness of the multifunctional additive to fuels relative to the reduction of CO, NO_x, C_mH_n, $PM_{2.5}$, carbon dioxide and oxygen consumption (taking into account fuel consumption data [18]), as well as relative to the reduction of benzo(α)pyrene ($e_{C_{20}H_{12}}$).

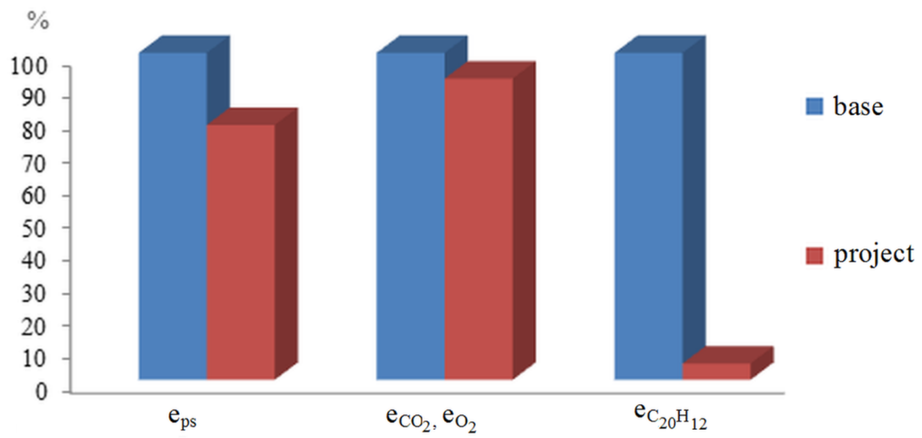


Figure 5. Effectiveness of the multifunctional additive application in preventing environmental damage

Thus, the assessment carried out demonstrates that the environmental protection measure under consideration significantly increases the environmental sustainability of vehicles. Given the 95 % reduction in benzo(α)pyrene emissions, and its high relative hazard, which is 3–5 times greater than the relative hazard of emissions of other pollutants under consideration, this effect of the additive application is of the highest environmental significance. A high level of environmental compatibility, substantial fuel-savings and low cost of implementation are significant arguments for the extensive use of the environmental protection measure proposed.

4. Conclusion

The need to make informed decisions on the selection of optimal measures that will improve the environmental sustainability of motor transport while taking into account the complexity of fully accounting for external factors makes it important to develop simplified approaches to assess the effectiveness of the implementation of the relevant environmental protection measures. An approach was proposed for assessing the effectiveness of environmental protection measures in the operation of motor vehicles and also considering externalities caused by emissions of polluting toxic substances, carbon dioxide and the consumption of oxygen during fuel combustion. The proposed approach allows the effectiveness of the environmental protection measure to reduce emissions of polluting toxic substances and corresponding environmental damage to be evaluated by calculating the relative change in the equivalent mass of emissions. The effectiveness of environmental protection measures at reducing carbon dioxide emissions and oxygen consumption during fuel combustion and to prevent appropriate environmental damage is proposed to be estimated from the calculation of the relative change in fuel consumption. The use of the proposed approach for assessing the effectiveness of use of the multifunctional fuel additive made it possible to give recommendations for its wide application. The developed simplified approach can be used in assessing the effectiveness of the environmental protection measures both for motor transport, and for stationary sources of atmospheric pollution.

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